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Geothermal Direct Use for Silkworm Cultivation as a CSR Program in Wayang Windu Geothermal Field: Thermal Energy Calculation Approach

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Abstract: Geothermal energy resources in West Java, Indonesia, are mostly utilized for electricity generation. Still, they can also be used for direct-use applications. Star Energy Limited, the operator of the Wayang Windu power plant located in Pengalengan and Kertasari Districts, West Java, plans to use non-commercial wells for silkworm cultivation, a community economic activity supported by the company's Corporate Social Responsibility initiatives. One silkworm farming group in the Wayang Windu field can produce 240 kg of cocoons per production cycle. Silkworm cultivation's thermal energy calculation was studied, including key components such as heat exchangers. This calculation will utilize a WWS-1 non-commercial heating well. The well can generate around 17 MW_t. Based on the calculations, it takes about 0.15 MW_t to make 10 kilograms of cocoons. It means it needs 3.7 MW_t per production cycle of a silkworm cultivation house so that the well can meet the heat requirements of silk yarn production. The heat of 3.7 MW_t is equivalent to 0.5 kg of coal or 1.4 kg of carbon dioxide (CO2). Therefore, the WWS-1 well can supply the energy requirements of three of the seven silkworm cultivation houses in the Wayang Windu area. The planned silkworm-growing project is proposed to be located near WWS-1, accessible through public roads, and managed by a third party with the community's help. The proposed plan for managing community development relies on geothermal energy. The geothermal developer provides equipment and facilities for direct use, handing over management to third parties like business cooperatives. Overall, this project has the potential to benefit the community and promote the use of clean energy in the production of goods. This project is an excellent case study of how geothermal energy may be used for community development without interfering with the main task of a geothermal field for generating electricity.

Keywords: Geothermal Direct Use, Silkworm Cultivation, Wells, CSR, Wayang Windu

1. Introduction

Indonesia has a geothermal potential of 28,910 MW_t that ranges in geothermal fluid enthalpy from low to high. It is distributed along a volcanic path from Sumatra, Java, Bali, East Nusa Tenggara, Celebes, and Maluku islands. With a total installed capacity of 2,356 MW_e, Indonesia is the second-largest geothermal energy producer in the world, after the United States[1, 2, 3].

In addition, developing geothermal energy along the so-called Ring of Fire of the Indonesian Islands is also crucial to the nation's energy security. In their study on energy security, Gima and Yoshitake[4] concluded that diversification of thermal power generation and innovation in renewable energy are crucial factors for island energy security. Consequently, the availability of geothermal energy power plant capacity should be the immediate objective of development.

West Java is one of the provinces containing 5,839 MW_t, or 20% of Indonesia's total geothermal potential[5]. Its geothermal power plant (GPP) potential has been exploited in several fields spanning eleven (eleven) districts. These fields include the 376.8 MW_e Gunung Salak geothermal field in Bogor Regency, the 270 MW_e GPP Darajat in Garut Regency, the 30 MW_e GPP Karaha in Tasikmalaya Regency, and the following three GGPs in Bandung Regency: GPP Wayang Windu (227_e MW), GPP Kamojang (235 MW_e), and GPP Patuha (55 MW_e)[6), 7)]. The six power plants produce a total of 1,193.8 MW_e. Geothermal energy is currently almost exclusively used to generate power.

In contrast to converting geothermal energy into other forms of energy, such as electrical energy, direct use uses heat energy or fluid directly from geothermal resources[8]. Geothermal direct use is not yet widespread in Indonesia. Only 11.8 GW is used for direct use, and about 9,600 GWh per year produce electricity[9),10)]. Direct use has environmental, social, and economic advantages that can stimulate the development of the local economy. Large-scale geothermal energy production has a larger environmental impact than direct use. This can assist minor businesses in the region that require these resources, thereby contributing to the expansion of the local economy. Geothermal activity influences economic growth in various ways, including making more power available, generating more revenue for the government, lowering the unemployment rate, extending the life of corporate social responsibility (CSR) programs, enhancing infrastructure, and attracting more tourists to a region[11]. Geothermal energy development has multiple advantages that will enhance the quality of life in remote areas and stimulate regional economic growth[12].

Furthermore, geothermal energy is a versatile renewable energy source that can be utilized directly for heating, drying, sterilizing, and pasteurizing, among other applications[13]. In Indonesia, geothermal resources are typically situated in hilly regions, surrounded by agricultural, plantation, forestry, breeding sectors, fisheries, and tourism destinations. This makes many direct-use geothermal energy applications a natural fit in these regions. For example, geothermal energy can dry and preserve various agricultural products, including tea, coffee, cocoa, coconut, etc. It can also be used for sterilizing growing agents, pasteurizing breeding products such as milk, heating rooms, and bathing in hot springs. Additionally, geothermal energy can be utilized in several other applications, such as the leather tanning industry, metal processing, and more[14].

Despite the versatility of geothermal energy, most direct-use applications in Indonesia, specifically in West Java, are used for bathing and swimming. According to estimates, the annual usage of geothermal energy for this purpose is 2.3 MW_t and 42.6 TJ[15), 16)]. However, there is significant potential to expand the use of geothermal energy in direct applications beyond bathing and swimming, thereby maximizing the possible benefits of this renewable energy source.

Despite the enormous geothermal energy supply in West Java, using this renewable energy source for direct applications still needs to be improved. Nevertheless, there are opportunities to increase the use of geothermal energy in direct applications by transforming unused wells into producing wells for geothermal power plants. This approach could provide a more sustainable and efficient use of geothermal energy, reducing the need to rely on non-renewable energy sources. Additionally, many agroindustries rely heavily on non-renewable energy fuel sources for various activities, such as drying, heating, sterilizing, and pasteurizing. Using geothermal energy could provide a more sustainable and cost-effective alternative to traditional energy sources for these activities, potentially creating significant sustainability benefits for the agroindustrial sector in West Java.

The local community has established a silkworm farming industry near the Wayang Windu geothermal field (WWGF), as warmth is crucial for cultivating silkworms. This sericulture is approximately 3.8 kilometers from the Wayang Windu GPP and 3 kilometers from a WWS well-pad of the WWGF. Geothermal energy can generate this heat, making it possible to use it as an alternative to traditional fuel sources. The geothermal field developer, Star Energy Limited, has made this possible by implementing a Corporate Social Responsibility (CSR) program. Star Energy Limited operates the GPP Wayang Windu, a 227 MW_e geothermal power plant. Implementing geothermal energy directly for silkworm farming presents an opportunity to reduce coal usage, which has traditionally been used as fuel for this type of cultivation. This will reduce carbon dioxide emissions, contributing to international efforts to combat climate change. Indonesia has pledged to reduce its greenhouse gas emissions by 29% by 2030 and 41% with international assistance as part of an international Agreement[17].

Using this context as a guide, the Research Center for Energy Conversion and Conservation, National Research and Innovation Agency (BRIN) intends to maximize the direct use potential of geothermal energy in West Java, particularly in the Wayang Windu Field. Therefore, this study will examine the thermal energy calculation of components for heat processes in silkworm farming with geothermal energy sources in the Wayang Windu region.

2. Potential Wayang Windu geothermal resources for direct use

Fig. 1 depicts a map of the WWGF, which is less than 141 kilometers southeast of Jakarta and less than 32 kilometers southwest of Bandung[18]. The WWGF is one of several operating high-temperature geothermal fields that produce energy sources in Pengalengan and Kertasari Districts, in the volcanic highlands south of Bandung Regency, West Java, Indonesia, including (from west to east) Patuha, Wayang Windu, Kamojang, Darajat, and Karaha Bodas. With a 400 MW proven reserve classification, the Wayang Windu geothermal resource has geothermal energy potential. 2 (Two) GPP units now utilize the steam produced by this field, each of which has a capacity of 1 x 110 MW_e and 1 x 117 MW_e. At Wayang Windu, 60 wells have been drilled, including 26 active production wells, 11 offline/shut-in wells, five active reinjection wells, six abandoned wells, five monitoring wells, and seven slim holes. Most wells are between 1120 and 2510 meters deep[19].

The geothermal fluid produced in the Wayang Windu field is two-phase, so a separator is placed to separate the steam from the hot water. The steam is routed to 2-unit turbines to generate electricity with a total capacity of 227

MW_e. At the same time, the separated hot water (or so-called brine) with a temperature of 175 – 180°C is reinjected into the earth via a green-colored brine pipeline, as depicted in Fig. 2. This pipeline is installed approximately 500 meters from the Malabar tea drying plant. The brine is an extremely viable heat source for direct application in the tea drying facility. Suyanto et, al[20] investigated the brine for direct-use application in tea withering and drying in the Wayang Windu geothermal area. The Malabar tea drying plant uses Industrial Diesel Oil (IDO) as the heat source for the withering and drying processes. The maximum product capacity of the Malabar is 63 metrics tons per day. Per year, the plant needs about 1.25 million liters. The separated brine from Wayang Windu geothermal power plant, with 55 kg/s flowrate and a temperature of 180°C can fulfill the substitution of IDO for all heating processes in the Malabar tea factory.

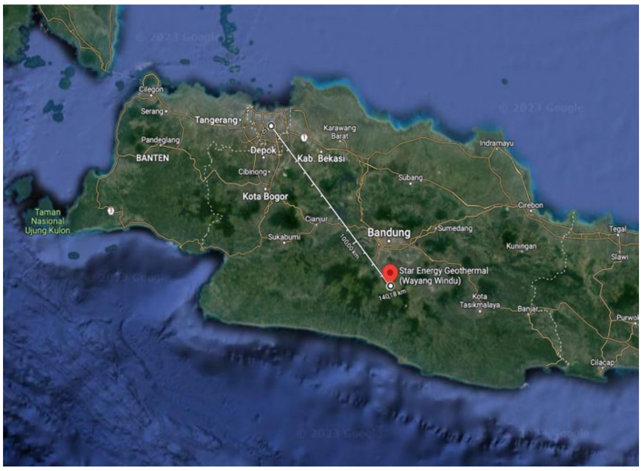

Fig. 1: Map of Wayang Windu geothermal field[18]

In some of the clusters near the WWGF, such as WWC, WWD, WWE, WWJ, WWP, WWQ, and WWR, there are small unproductive wells, or non-commercial wells, that can be utilized directly as heat sources in addition to brine (as shown in Fig. 2). This approach can provide a cost-effective and sustainable method of using geothermal energy for direct-use applications in the agricultural and agroindustrial sectors. Fig. 2 illustrates the locations of geothermal wells, pipelines, and various agricultural products near the WWGF. In addition, Table 1 details the characteristics of the heat sources at WWGF that are suitable for direct-use applications, including five wells, brine from separators, and condensate from the cooling towers of the Wayang Windu power plant, based on field research findings at WWGF. By leveraging these available heat sources, it may be possible to expand geothermal energy for direct applications in these regions, promoting sustainable rural development and reducing reliance on non-renewable energy sources.

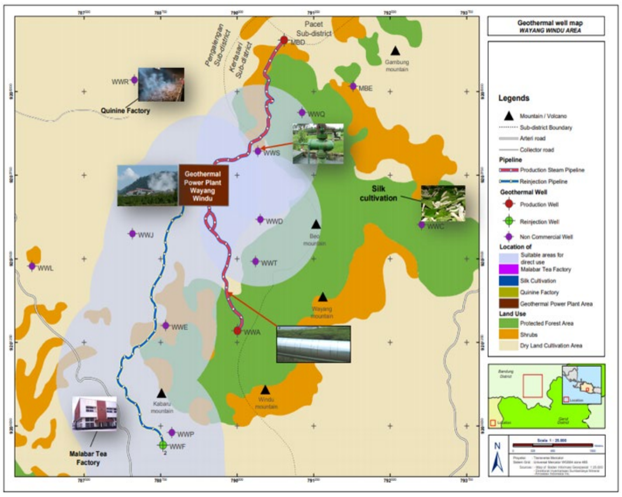

Fig. 2: Map of Wayang Windu geothermal wells

Table 1. Geothermal heat sources which are potential for direct use

Nr.	Well name	Fluid type	Well-head pressure	Reservoar temp. (°C)	Flow-rate	Piping	Remarks
1.	WWD-1 (Idle Well)	2 Phase, x=0.3, h=1400 (kJ/kg)	N/A	298 @ 1996m	N/A	No	Production Well $4MW_e$
2.	WWS-1 (Idle Well)*	x=0.6889	N/A	194 @ 1300m	11.85 kg/sec (=42.66 ton/hr)	Yes	Heating-up, $0.5MW_e$ @ 11 barg
3.	WWR-SH (plugged)	N/A	N/A	253 @ 1520m	N/A	No	Close to PTPN8's quinine factory
4.	WWW-1 (Injection Well)	2 Phase, x=0.3, h=1400 (kJ/kg)	N/A	262 @ 1941m	N/A	No	Injection Well, $5MW_e$ @ 9 barg
5.	WWW-2 (Injection Well)	-	N/A	217 @ 1200m	N/A	No	Injection Well, $2MW_e$ @ 6 barg

6.	Brine (from Separator)	Hot water	10 bar	180	75 kg/s (=270 t/hr)	Yes	Pipe to Reinjection Well WWF Pad
7.	Condensate (from Cooling Tower)	Warm water	N/A	40	55 kg/s (=198 t/hr)	Yes	Pipe to Reinjection Well WWF Pad

*In this study, WWS-1 will be utilized as a heat source to substitute coal for direct-use silkworm culture products.

Table 2 outlines several agricultural and agro-industrial products close to the WWGF that can use geothermal energy as an alternative fuel source, based on WWGF field research findings. The agro-industrial products identified include quinine, silk, mushrooms, and tea. Currently, the primary heat sources for silkworm cultivation and withering and drying tea leaves at Malabar tea plantations are coal and Industrial Diesel Oil (IDO), respectively. However, the heat energy in the brine (hot water) at point 6 in Table 1 can replace IDO, as has previously been discussed[15].

Table 2. Potential agricultural products for direct use applications in Wayang Windu

Nr.	Product	Capacity	Heating Process	Temp.	Activity	Remarks
1.	Quinine	Quinine powder, 25 ton/year	Dyring by sun heat	-	Withering	Firewood demand is relatively small.
			Drying by hot air. Fuel: Firewood for 7 hours	80-90°C	Decrease the water content to 60%	
2.	Silk	Silkworm, 6-8 box/room	Room warming by using coal	25-27°C	Keep the room temperature at around 25°C	Coal consumption = 1 ton/month. If cocoon production is high, need an oven process (± 95°C).
		Silk yarn, 1-2 kg/day	Boiling cocoon by using coal	70-80°C	-	
3.	Mushroom	The community wishes to develop mushroom industry again.				
4.	Tea (Malabar Plantation)	65 ton per day	Withering Process	25°C	To decrease the water content to 50% (8-10 hours in the rainy season, and 2-3 hours in the dry season	IDO:1,25 million liter/year
			Drying Process	120°C	To decrease the water content up to 2%	

From Table 1, the non-commercial well WWS-1 (idle well) is the most potential well that will be employed as a potential source of geothermal energy for creating direct-use silkworm culture products. Silkworm cultivation is a community economic activity that has received support from the Wayang Windu geothermal company "Star Energy Ltd." as part of its Corporate Social Responsibility (CSR) initiative. The silkworm farming method can employ geothermal fluids, and in its implementation, the cultivation facility is positioned near the WWS-1 well.

3. Silk Yarn Industry

Silk is a soft-textured fabric initially discovered in China by Empress XI Si Ling Shi, wife of Huang Ti (2640 BC)[21]. Indonesia ranks ninth worldwide in silk production. In Pengalengan District of Bandung Regency, a community organization manages the silk yarn industry in the Wayang Windu geothermal area. There are currently seven silkworm cultivation groups and approximately ninety hectares of mulberry trees, whose leaves serve as a feeding source for silkworms. One silkworm farming group can produce 240 kg of cocoons per production cycle. In this study, it is possible to determine how many silkworm cultivation groups can successfully replace their fossil fuels with geothermal energy from WWS-1.

In addition to being a source of food for silkworms, mulberry trees also have environmental benefits. They positively impact soil health and water conservation, making them an important component of sustainable agriculture. Using intercropping strategies to cultivate mulberry plants in the forest positively impacts reforestation, providing a more effective and environmentally friendly alternative to conventional reforestation practices. Perhutani and Star Energy Limited provide assistance for community development to the silk yarn industry, enhancing the viability of regional economies and social well-being. Perhutani is a State-Owned Enterprise (SOE) in Indonesia responsible for managing production forests.

The cocoon is the raw material used to make silk yarn. In one silkworm farming group in the Wayang Windu field, there is a 13-by-8-meter house producing 240 kg of cocoons per production cycle. These cocoons require 8 tons of mulberry leaves from around 2 hectares of mulberry trees. These cocoons will generate 1 to 1.5 kilograms of silk yarn daily. The silk yarn industry uses 1 ton of coal monthly as its primary energy source for heating and boiling.

The silk yarn industry can be divided into two major processes: the silkworm cultivation process and the silk yarn spinning process[22]. Energy is required during room heating, specifically during the silkworm culture's ova, larva, and pupa phases. The energy required for spinning silk yarn occurs throughout the oven process. As an alternative to coal, one of the geothermal wells in the Wayang Windu geothermal area can be used as the energy source for these processes.

3.1 The silkworm cultivation process

The method for cultivating silkworms comprises the five processes depicted in Fig. 3 and described below.

a. *Preparation* involves preparing silkworm egg seeds, preparing and sterilizing the silkworm raising room, and feeding silkworms mulberry leaves. This entire procedure takes 1-10 days.

b. *Ova* is the procedure by which silkworm eggs are incubated. Eggs are distributed across the hatching box or tray and covered with a thin sheet of white paper. This box is then placed in a cool environment shielded from direct sunlight and maintained between 25 and 28°C and 75% and 85% relative humidity. After discovering blue spots on the eggs, the egg box was shrouded in black linen for two days. This incubation period lasts between 10 and 14 days.

c. *Larva (5 Instars)* - At this stage, the little or young silkworms are separated from the incubator room and stored in a separate building called the silkworm house. The silkworm home was disinfected with a 95:5 chalk and chlorine mixture[23]. There were numerous shelves in this residence. The freshly cut, young mulberry leaves are then displayed on shelves. The newborn silkworms are then placed on the mulberry leaves. Little silkworms are fed three times daily, in the morning, midday, and night[24]. The silkworms will molt at each instar during their rest period. When at least 90% of the silkworms are asleep and have stopped eating, the windows and vents are opened to allow air circulation. The ideal temperature for the room is between 24 and 26°C. This entire procedure takes 27 days.

d. *Pupa (cocoon)* refers to raising mature silkworms to cocoon in the following silkworm home. Before the grown silkworms are removed, all shelves in the silkworm house for grown silkworms are disinfected using a 90:10 mixture of lime and chlorine powder. After that, clean and fresh mulberry leaves and their branches are placed on the shelves, followed by the silkworms. These mulberry leaves don't need to be sliced and will provide excellent nourishment for silkworms. The adult silkworm will spin a cocoon after 14 days.

e. *Imago* is when a caterpillar in a cocoon matures and becomes a butterfly. Before the caterpillar can transform into a butterfly, the pupa must be extracted. These cocoons are the raw ingredient for silk thread.

The timeline process of silkworm cultivation is shown in Fig.3.

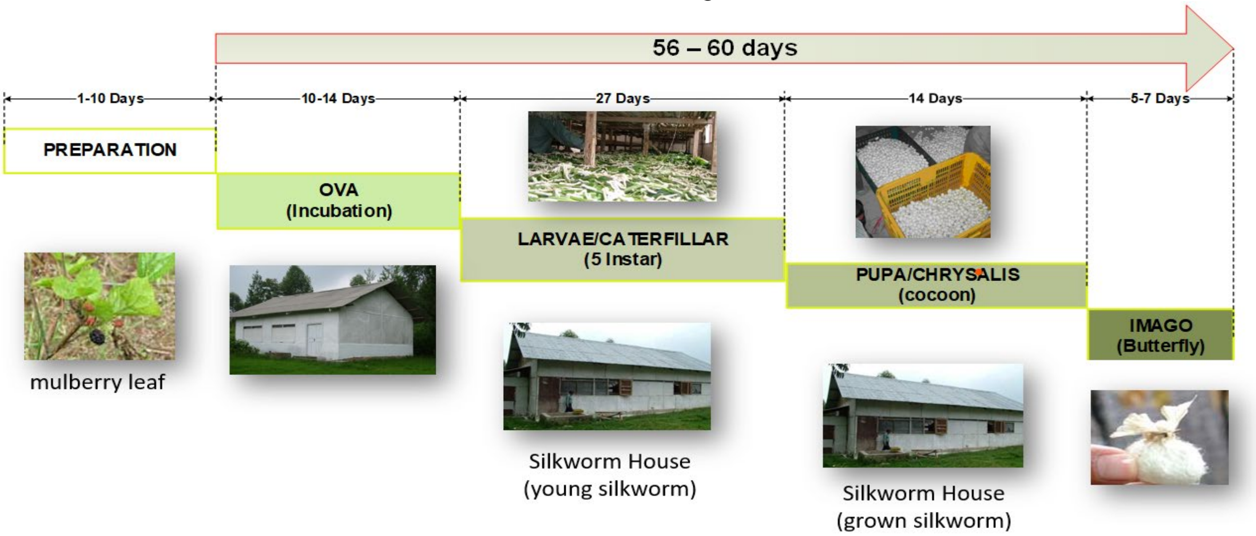

Fig. 3: Process timeline of silkworm cultivation

3.2 The yarn spinning process

Fig. 3 depicts the four steps of the silk yarn spinning process, described below.

a. *Cooking* is the process of boiling the cocoons to make them soft. Therefore, the cocoon fibers become loose, and the ends of the silk threads of the cocoons are readily extracted. This boiling is done at temperatures between 95°C and only takes a few minutes. From the data survey, the ambient pressure condition in the area is 833 millibars.

b. The *oven* is heating the cocoons to kill the caterpillars in the cocoons so they don't grow into butterflies. This oven method is carried out if the cocoon production surpasses the capability of the boiling or reeling gear. The oven temperature is kept around 80°C at various intervals to ensure the caterpillars perish. If the oven temperature is too high and it takes a long time, the cocoons break easily.

c. *Reeling* is the process of extracting the end of a silk thread from a cocoon and then rolling it in a reeling machine.
d. *Winding* is the process of rewinding yarn in a winding machine to produce a roll ready for market with a particular length/weight.

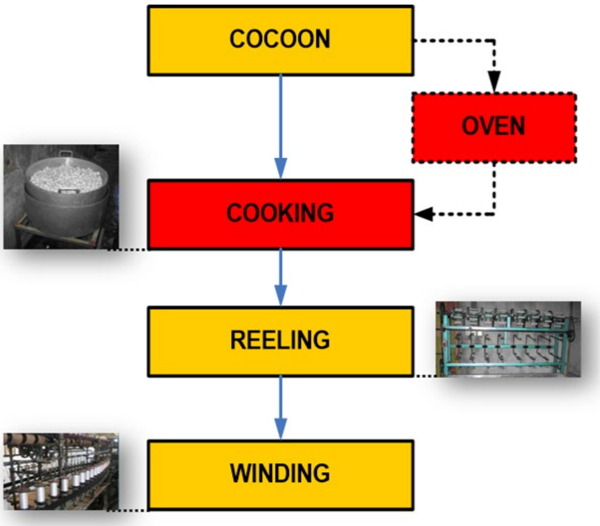

Fig. 4: Yarn spinning process

4. The calculation of system and heat-exchanger components for the silk yarn cultivation process

4.1 The work principle and main character of silk yarn cultivation process (thermodynamic cycle)

Fig. 5 represents the thermodynamic work concept in a silk yarn cultivation system powered by geothermal energy. The system comprises two primary closed loops: (1) a geothermal energy loop and (2) a working fluid-fresh water loop. The geothermal energy loop system includes a Well WWS-1, a separator, a steam generator, and a reinjection well. In contrast, the working fluid-fresh water loop system includes a water tank, steam generator, silkworm rooms/houses, oven, and cooking unit.

a. **Geothermal energy loop**: A separator splits the geothermal fluid into steam and brine. With a heat exchanger called a steam generator, steam evaporates the working fluid (in this research, water). In the meantime, the heated water (brine) returns to the ground (reinjection well) or a pond. In addition, additional brine from the steam generator flows into the reinjection well.
b. **Working fluid-fresh water loop**: In addition, the steam from the working fluid that emerges from the steam generator is used for the heating process, the boiling process (cooking), and the oven process. The condensed working fluid will return to the pool, then be circulated using a feed pump to the evaporator, and so on, in the working fluid loop. A hermetic centrifugal system, with an efficiency of approximately 55%, is one feed pump that can be utilized (the ratio of hydraulic power to electricity consumption). The adiabatic efficiency is assumed to be 75%, though[25),26)].

4.2 Project data

This computation will employ a WWS-1 from a non-commercial well[27)]. Drilled on December 17, 1997, WWS-1 is heating up well. WWS-1 is approximately 1.5 kilometers north of the unit I and II (227 MW_e) power plants, as shown in Fig. 2. The following is data from the WWS-1 well that is a thermodynamic parameter:

Total Flow Rate=11.85 kg/sec
Separation Pressure= 5 bar (temperature=151.8°C)
Steam Flow Rate = 8.17 kg/sec
Dryness= 68.89%

Usually, geothermal fluids have a high silica content that causes silica scaling problems[28),29)]. If the geothermal heat load from WWS-1 can be extracted without generating a technical issue such as scaling, it can produce 16,983 kW_t or 17 MW_t of heat load, as calculated below [30)].

$$\dot{Q}_{th} = \dot{m}_{st}(h_i - h_o) \qquad (1)$$

where Q_{th} is the geothermal heat load, $\dot{m}_{st}$ is the vapor steam flow rate, h_i and h_o are the enthalpies of geothermal fluid entering and exiting a steam generator, respectively. h_i is enthalpy at its saturation vapor, while h_o is enthalpy at its saturation liquid. Due of the saturation process, the liquid output temperature from the steam generator is the same as the inlet temperature of 151.8° C. Silica scaling will not develop at this outlet temperature, while geothermal fluid at the Wayang Windu Geothermal Field will form a scale at 147.5°C [20), 31)]. This available heat of 16,983 kW can be used to replace the energy needed by equipment for heating, drying, and cooking operations.

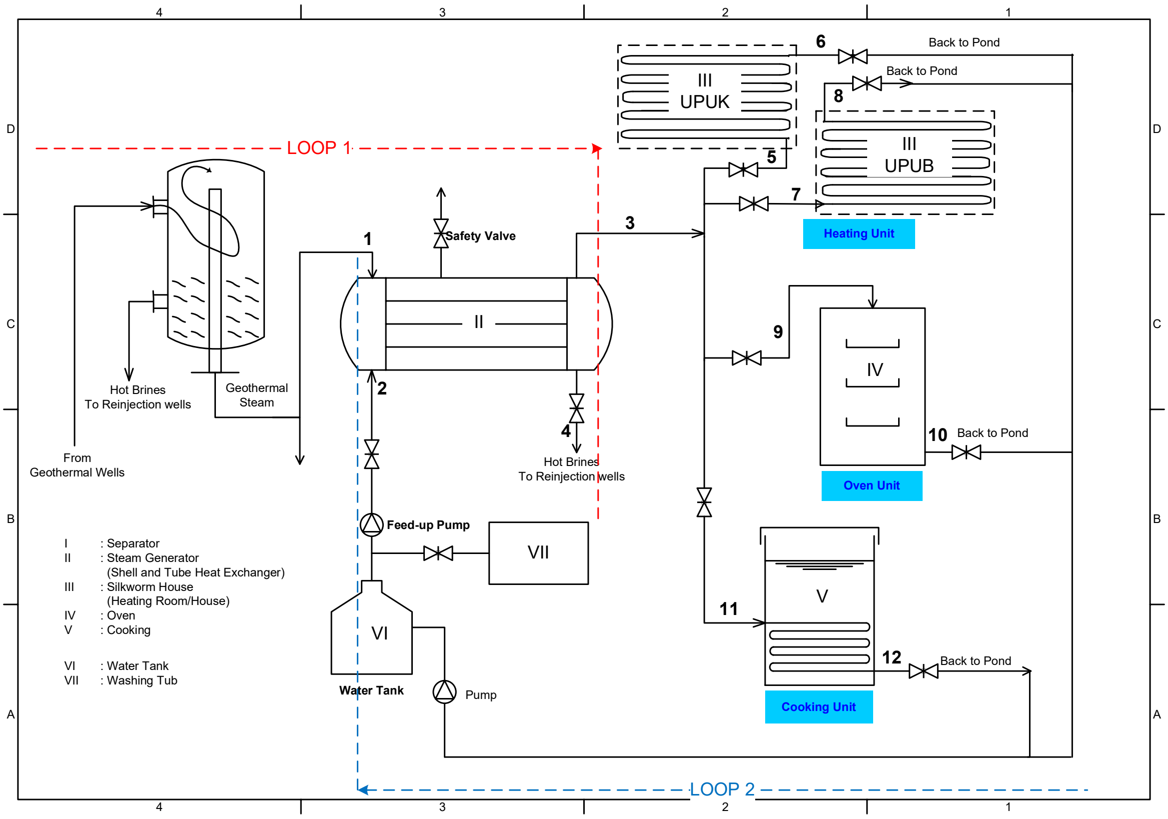

Fig. 5: Schematic of a silk yarn cultivation system

4.2.1 Heat and mass balance

Using a thermodynamic principle or software, a mass and heat balance calculation may be performed with the thermodynamic parameters from the WWS-1 well and the parameters from the silkworm rearing process and the silk yarn spinning process. The software can calculate fluid thermodynamic property values and run simulations for each operating state. The computation is performed with the following assumptions:

- The outside air temperature ranges from 15-23°C[20), 32)]. For calculating heat and mass balance, the average ambient temperature is assumed to be 18°C.
- The condensation temperature of geothermal steam from the steam generator is a saturated liquid temperature of 5 bar, where no silica scaling is expected.
- The air in the heating house (UPUK) for young silkworm house and (UPUB) for grown silkworm house) only transfers heat convectively, and radiation conduction is negligible because convection currents move quickly.
- The house is perfectly insulated, and no heat is lost to the room heating system.
- The inlet water temperature of the steam generator is 20°C.
- The media temperature before heating and the temperature in the oven room were 18°C and 80°C, respectively.
- The boiling temperature is 95°C.
- The outlet steam temperature on the freshwater side is 115°C.
- A unit or house for young silkworms (UPUK):
  * The air temperature in UPUK during heating is 28°C.
  * The volume of air at UPUK is 7m * 5m * 3.1m.
  * The trays for spreading the cocoons are 5m * 5m * 2cm and consist of 2 trays.
- A unit or house for grown silkworms (UPUB):
  * The air temperature in UPUB during heating is 26°C.
  * The volume of air at UPUB is 13m * 8m * 3.1m.
  * The trays for spreading the cocoons are 8m * 8m * 2cm and consist of 2 trays.
- The insulation materials for the UPUK and UPUB heating houses consist of:
  * The upper wall consists of 2 layers (plastic and tarpaulin) with a thickness of 1 mm and 2 mm, respectively, and the area of the upper wall of the UPUK and UPUB are 2 * ((2.1 * 7) + (2.1 * 5))) m^2 and 2 * ((2.1 * 13) + (2.1 * 8)) m^2.
  * The lower wall consists of 1 concrete layer with a thickness of 140 mm, and the area of the UPUK and UPUB lower walls is 2 * ((1 * 7) + (1 * 5)) m^2 and 2 * ((1 * 13) + (1 * 8)) m^2.
  * The floor consists of 1 layer (concrete) with a thickness of 100 mm, and the areas of the UPUK and UPUB floors are 7 * 5 m^2 and 13 * 8 m^2, respectively.
  * The roof consists of 1 layer, namely a tarp with a thickness of 2 mm, and the areas of the UPUK and

UPUB are 7 * 5 m^2 and 13 * 8 m^2, respectively.

- UPUK and UPUB are heated for 24 hours.
- The outer diameter of the pipe to be used as a heat conductor from the separator to the steam generator is 2"(inches) with schedule 40.
- The materials for the cocoon oven and cocoon cooking machines are carbon steel and stainless steel with a thickness of 10 mm each. Both the oven and cooking units are insulated with glass wool material.
- The size of the cocoon oven machine is 1.14 m * 1.14 m * 1.7 m, while the size of the cocoon boiling machine is 0.6 m * 0.6 m * 1.5 m.
- The average wind speed at the location is 2 m/s or 7.2 km/h.
- The capacity of the cocoon oven machine is 10 kg with an oven period of 1 hour, while the capacity of a cocoon boiling machine is 10 kg with the cooking period of 3 hours.

The heat and mass balance process of heating unit, drying unit, cooking unit and steam generator is written as follows[23), 27)].

a. Heating process for young (UPUK) and grown (UPUB) silkworm houses.

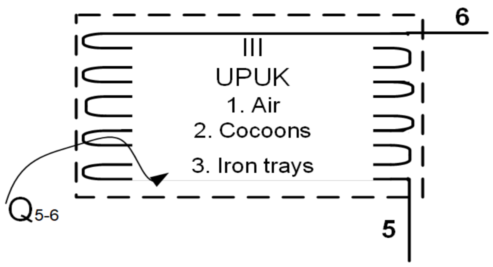

Fig. 6: Energy balance in the heating process system for young silkworm

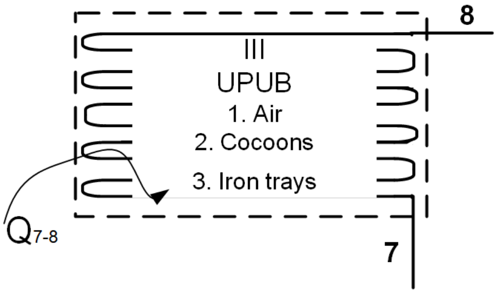

Fig. 7: Energy balance in the heating process system for grown silkworm

The energy balance in the heating process system for young and grown silkworms is shown in Fig. 6 and Fig.7. Generally, the heating process for young and grown silkworm houses can consist of air, cocoons, and iron trays to put the cocoons in. Referring to Fig. 6, the formula to calculate the required heat load in the young silkworm houses (UPUK) is as follows:

$$E_{UPUK,I} + Q_{UPUK} = E_{UPUK,II} \qquad (2)$$

$$Q_{UPUK} = \Delta E_{UPUK} \qquad (2a)$$

$$\Delta E = [m_{a,UPUK} \times (h_{a,UPUK,II} - h_{a,I})] + [m_{c,UPUK} \times Cp_c \times (T_{UPUK,II} - T_I)] + [m_{t,UPUK} \times Cp_t \times (T_{UPUK,II} - T_I)] \qquad (2b)$$

$$\dot{Q}_{UPUK} = \frac{Q_{UPUK}}{t_{heating}} \qquad (3)$$

where, $E_{UPUK,I}$ and $E_{UPUK,II}$ are the initial and final energies of the house, respectively. Q_{UPUK} is the heat energy supplied to the house. $m_{a,UPUK}$, $m_{c,UPUK}$, and $m_{t,UPUK}$ are the masses of air, cocoons, and iron trays, respectively. $h_{a,I}$ and $h_{a,UPUK,II}$ are the air enthalpies of the initial and final conditions, respectively. Cp_c, and Cp_t are the specific heat at constant pressure of cocoons and iron trays, respectively. The temperature of the first and final conditions are symbolized by T_I and $T_{UPUK,II}$, respectively. $\dot{Q}_{UPUK}$ is the heat energy supplied to the house at a certain time ($t_{heating}$).

Heat loss through the house layers is calculated using the following equation:

$$\dot{Q}_{loss,w} = \frac{T_{UPUK,II} - T_{air,ambient}}{\frac{1}{h_i} + \sum_1^n \frac{t_{w,n}}{k_{w,n}} + \frac{1}{h_o}} \times A_w \qquad (4)$$

where, $\dot{Q}_{loss,w}$ is the heat loss for each wall of the house, and A_w is the surface area of each house wall. h_i and h_o are the air convective heat transfer coefficients inside and outside UPUK, respectively. $t_{w,n}$ is the n-layer thickness of each wall, and $k_{w,n}$ is the thermal conductivity of n-layer thickness of each wall.

So, the total heat load for each house is ($\dot{Q}_{5-6}$):

$$\dot{Q}_{5-6} = \dot{Q}_{UPUK} + \dot{Q}_{loss,w} \qquad (5)$$

The need for steam ($\dot{m}_{s,UPUK}$) in the UPUK unit is calculated as follows:

$$\dot{Q}_{5-6} = \dot{m}_{s,UPUK} \times (h_{s,in} - h_{c,out}) \qquad (6)$$

The enthalpies of steam entering and condensate exiting the UPUK units are denoted by $h_{s,in}$ and $h_{c,out}$, respectively.

Referring to Fig.7, the formula to calculate the required heat load in the UPUB ($\dot{Q}_{7-8}$) and the need for steam in the UPUB is similar to eq. (2) – (6).

b. Oven unit

Fig. 8 shows the energy balance of the oven unit. The process in the oven unit is rather similar to that in the heating unit (UPUK or UPUB). The difference lies in the final conditions in each of these processes. The oven unit heats the system to 80°C, whereas the heating unit only warms the room to 26-28°C. This calculation disregards the cocoon's water content because the intent of the process in this unit's oven is to kill the cocoon. The equation formula in the oven unit is as follows:

$$E_{oven,I} + Q_{oven} = E_{oven,II} \qquad (7)$$

$$Q_{oven} = \Delta E_{oven} \quad (7a)$$

$$\Delta E = [m_{a,oven} \times (h_{a,oven,II} - h_{a,I})] + [m_c \times Cp_c \times (T_{oven,II} - T_I)] + [m_t \times Cp_t \times (T_{oven,II} - T_I)] \quad (7b)$$

$$\dot{Q}_{oven} = \frac{Q_{oven}}{t_{oven}} \quad (8)$$

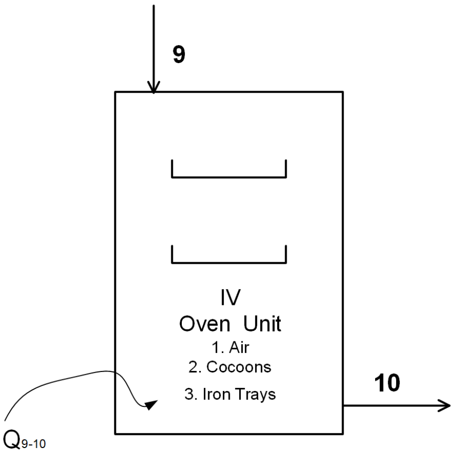

Fig. 8. Energy balance in the oven unit

where $E_{oven,I}$ and $E_{oven,II}$ are the initial and final energies of the oven, respectively. Q_{oven} is the heat energy supplied to the oven. $m_{a,oven}$, $m_{c,oven}$ and $m_{t,oven}$ are the masses of air, cocoons and iron trays, respectively. $h_{a,I}$ and $h_{a,oven,II}$ are the air enthalpies of the initial and final conditions in the oven, respectively. Cp_c, and Cp_t are the specific heat at constant pressure of cocoons and iron trays, respectively. The temperatures of the first and final conditions are symbolized by T_I and $T_{oven,II}$. $\dot{Q}_{oven}$ is the heat energy supplied to the oven at a certain time (t_{oven}).

Heat loss through the oven layers is calculated using the following equation:

$$\dot{Q}_{loss,oven} = \frac{T_{oven,II} - T_{air,ambient}}{\frac{1}{h_i} + \sum_1^n \frac{t_{w,n}}{k_{w,n}} + \frac{1}{h_o}} \times A_w \quad (9)$$

where $\dot{Q}_{loss,oven}$ is the heat loss for each wall of the oven unit, and A_w is the surface area of each oven wall. h_i and h_o are the air convective heat transfer coefficients at the inside and outside of the oven unit, respectively. $t_{w,n}$ is the n-layer thickness of each wall, and $k_{w,n}$ is the thermal conductivity of the n-layer thickness of each wall.

The need for steam ($\dot{m}_{s,oven}$) in the oven unit is calculated as follows:

$$\dot{Q}_{9-10} = \dot{m}_{s,oven} \times (h_{s,in} - h_{c,out}) \quad (10)$$

c. Boiling process for cooking unit

The system of cooking units can consist of fresh water and cocoons. The energy balance in the cooking unit is shown in Fig. 9.

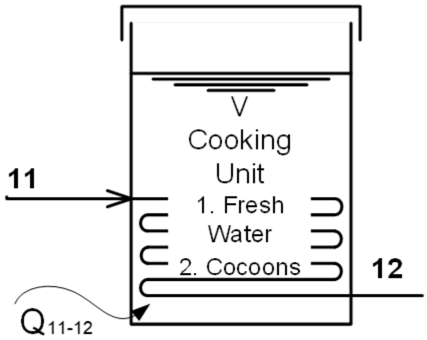

Fig. 9. Energy balance in cooking unit

The formula to calculate the required heat load in the cooking unit is as follows:

$$E_{cooking,I} + Q_{cooking} = E_{cooking,II} \quad (11)$$

$$Q_{cooking} = \Delta E_{cooking} \quad (11a)$$

$$Q_{cooking} = [m_{w,cooking} \times (h_{w,cooking,II} - h_{w,I})] + [m_{c,cooking} \times Cp_c \times (T_{cooking,II} - T_I)] \quad (11b)$$

$$\dot{Q}_{cooking} = \frac{Q_{cooking}}{t_{cooking}} \quad (12)$$

where, $Q_{cooking}$ is the heat energy supplied to the cooking system. $m_{w,cooking}$ and $m_{c,cooking}$ are the masses of fresh water and cocoon in the cooking system, respectively. $h_{w,I}$ and $h_{w,cooking,II}$ are the water enthalpies of the initial and final conditions in the oven, respectively. Cp_c is the specific heat at constant pressure in the cocoon. T_I and $T_{cooking,II}$ are temperatures at the first and final conditions, respectively.

Heat loss through the boiling layers is calculated using the following equation:

$$\dot{Q}_{loss,cooking} = \frac{T_{cooking,II} - T_{air,ambient}}{\frac{1}{h_i} + \sum_1^n \frac{t_{w,n}}{k_{w,n}} + \frac{1}{h_o}} \times A_w \quad (13)$$

where, $\dot{Q}_{loss,cooking}$ is the heat loss for each wall of the cooking unit, and A_w is the surface area of each cooking wall. h_i and h_o are the water and air convection heat transfer coefficient at inside and outside of the cooking unit, respectively. $t_{w,n}$ is the n-layer thickness of each wall, and $k_{w,n}$ is the thermal conductivity of n-layer thickness of each wall.

The need for steam ($\dot{m}_{s,cooking}$) in the cooking unit is calculated as follows:

$$\dot{Q}_{11-12} = \dot{m}_{s,cooking} \times (h_{s,in} - h_{c,out}) \quad (14)$$

d. Steam generator

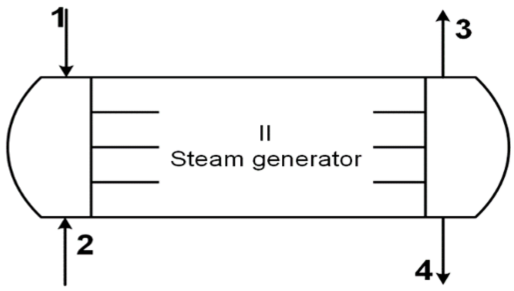

Fig. 10. Steam generator

The schematic system of the steam generator is shown in Fig. 10. In the steam generator, the fresh water is heated by the geothermal steam from the separator. The calculation formula used in the steam generator is as follows:

$$\dot{Q}_{1-4} = \dot{Q}_{2-3} \quad (15)$$

$$\dot{m}_{geo} \times (h_1 - h_4) = \dot{m}_{fw} \times (h_3 - h_2) \quad (16)$$

where, $\dot{Q}_{1-4}$ is the energy supplied by the geothermal steam, and where $\dot{Q}_{2-3}$ is the energy of the fresh water. $\dot{m}_{geo}$ and $\dot{m}_{fw}$ are the mass flows of the geothermal fluid and the fresh water, respectively. The enthalpies of geothermal fluid entering and exiting the steam generator are denoted by h_1 and h_4, respectively. H_1 is the enthalpy of geothermal fluid at vapor saturation, whereas h_4 is the enthalpy of geothermal fluid at liquid saturation. The enthalpy of fresh water entering the steam generator is denoted by h_2, whereas h_3 is the enthalpy of saturated steam.

e. Heat loss through the pipe

The pipe used to flow fresh water in this silkworm cultivation system is not insulated, so the heat loss through the pipe must be considered and calculate using the equation as follows[33),34),35)]:

$$h_{loss,pipe} = \frac{T_{o,w} - T_{air,ambient}}{\frac{1}{h_{air,pipe}} + \frac{t_{pipe}}{k_w}} \quad (17)$$

$$h_{air,pipe} = V_{pipe} \times \frac{k_{o,A}}{OD_{pipe}} \quad (18)$$

$$V_{pipe} = 0{,}266 \times Re_{pipe}^{0.85} Pr_{o,A}^{0.33} \quad (19)$$

where $h_{loss,pipe}$ is the heat loss through the pipe. $T_{o,w}$ is the outside wall temperature. $T_{air,ambient}$ is the ambient temperature. t_{pipe} is the thickness of the pipe. k_w is the thermal conductivity of the wall. $k_{a,A}$ is the thermal conductivity of the air outside the pipe. OD_{pipe} is the outside diameter of the pipe, while Re and Pr are the Reynold number and Prandtl number, respectively.

4.2.2 EES – Software for analysis

The Engineering Equation Solver (EES) software is utilized to evaluate the thermodynamic parameters of the working fluid and to execute calculations from the primary component systems, such as a heat exchanger (HE), for every operating situation[36)]. Numerically, the EES software can resolve linear, nonlinear, complex variable and optimization problems. It offers a vast library of built-in thermophysical properties and mathematical functions, and users can also upload their own data. However, it is important to note that EES does not solve engineering problems; it only solves user-supplied equations. Therefore, the user must comprehend and construct the problem using relevant physical rules and relationships. By utilizing EES, users can save time and effort when solving generated mathematical equations, enabling large engineering problems unsuitable for the manual calculation to be tested and parametric analyses to be performed quickly and easily. This study uses the EES software to analyze and evaluate the system's thermodynamic behavior and heat transfer characteristics.

4.2.3 Calculation results

The following is a summary of the major components of the silkworm cultivation system. The thermal heat requirements of the young silkworm house (UPUK) and the grown silkworm house (UPUB) are 26.8 kW_t and 50.5 kW_t. Comparatively, the oven unit with a capacity of 10 kg cocoons per 3 hours requires 3.9 kW_t, while the cooking unit with a capacity of 10 kg cocoons per hour requires 48.8 kW_t.

HEATING UNIT

1. Young silkworm house (UPUK)
   a. Steam flow rate = 0.1 ton/hr
   b. Inlet Temperature = 115°C
   c. Room Temperature = 28°C
   d. Heat Load = 26.8 kW_t
2. Grown silkworm house (UPUB)
   a. Steam flow rate = 0.1 ton/hr
   b. Inlet Temperature = 115°C
   c. Room Temperature = 26°C
   d. Heat Load = 50.5 kW_t

OVEN UNIT

a. Steam flow rate = 0.02 ton/hr
b. Inlet Temperature = 115°C
c. Oven Temperature = 80°C
d. Heat Load = 3.9 kW_t

COOKING UNIT

a. Steam flow rate = 0.2 ton/hr
b. Inlet Temperature = 115°C
c. Boiling Temperature = 95°C
d. Heat Load = 48.8 kW_t

The Steam Generator parameters are the sum of the parameters for heating, drying, cooking, and heat loss per unit. The calculation results for the thermal heat output of the steam generator are 155.9 kW_t, as shown below. The heat source for the steam generator is provided by the WWS-1 well.

STEAM GENERATOR

Working fluid (freshwater side)

a. Steam flow rate = 0.3 ton/hr
b. Inlet Temperature = 20°C
c. Outlet Temperature = 115°C

Geothermal fluid side

a. Steam flow rate = 0.3 ton/hr
b. Inlet Temperature = 151.8°C @ 5 bar
c. Outlet Temperature = 151.8°C
d. Heat Load (Power) = 155.9 kW_t

To produce 240 kg of cocoons every production cycle, a house of silkworm cultivation will require 3.7 MW_t. Therefore, the WWS-1 well can supply the energy requirements of three of the seven silkworm cultivation houses in the Wayang Windu area.

The amount of coal required to produce 1 kW of heat depends on the coal's energy content and the heating process's efficacy. The energy content of one ton of coal is approximately 24 million British thermal units (MMBTU). The quantity of coal required (in tons) equals the required Energy (in BTU) divided by the Energy content per ton of coal, which equals 0.0001422 tons for 3,412 BTU per 24 million BTU/ton. A reasonable estimate suggests that one kilowatt of heat would be produced by consuming approximately 0.0001422 tons of coal. However, coal's energy content varies, and the efficiency of the heating process can influence the amount of coal required. Thus, 3.7 MW_t of geothermal heat can replace 0.5 tons of coal, according to this study.

The carbon dioxide (CO_2) emissions from burning 1 kg of coal depend on its carbon content, which typically ranges from 40% to 90%. A preliminary estimate suggests a 75% carbon content produces around 2.86 kg of CO_2. However, this estimate may vary depending on the coal's properties, impurities, and combustion efficacy. Emission control technologies and combustion efficacy can also affect actual CO_2 emissions. In light of this research, 0.8 tons of coal can generate 1.4 kilograms of CO_2.

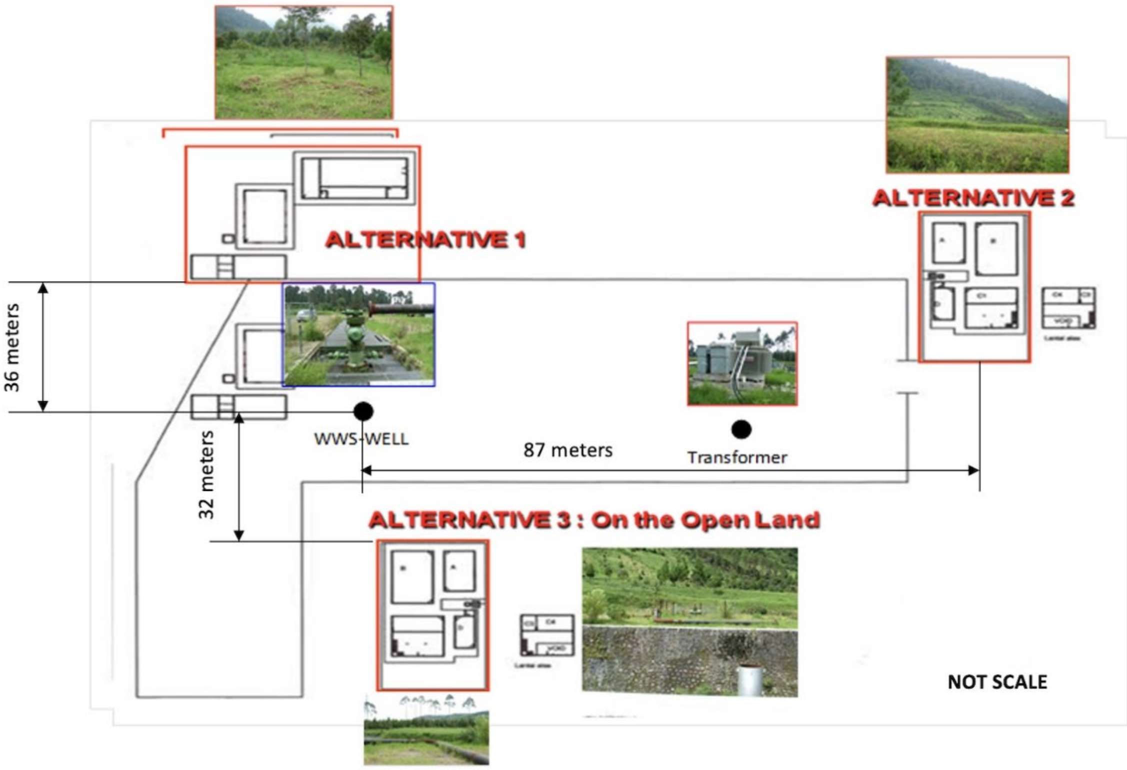

Fig. 11: Location options for silkworm cultivation process

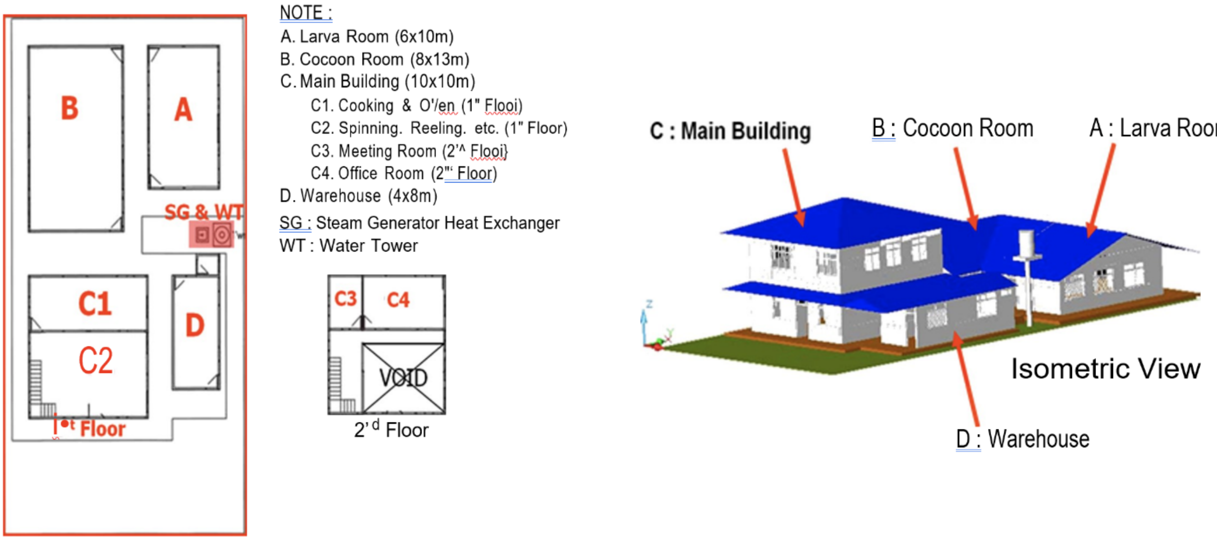

Fig. 12: The layout of the silkworm cultivation process

5. Project location for silk cultivation

The planned silkworm growing project should be located near a hot well, specifically WWS-1 in the Wayang Windu Geothermal Area in West Java (see Fig. 9). Fig. 11 illustrates three alternate project locations, all adjacent to the WWS well pad (130 m x 146.5 m). The location of the first alternative project is approximately 36 meters away from WWS and 6.7 meters above WWS. Contouring and access to the site are restricted to the right and left. The second alternate project location is 87 meters from the WWS and in front of the well pad's entrance; the terrain is also shaped. In the meantime, the third potential project site is 32 meters from WWS and is accessible through public roads or asphalt. The elevation in the third alternative is 4 meters from the asphalt road. Alternative 3 is the best location for the silkworm cultivation project based on distance and accessibility. However, its area is just 20 by 36 feet.

6. The layout of silkworm cultivation and piping system

Fig. 12 illustrates the layout of a silkworm cultivation project on a plot of land measuring 20 meters by 36 meters (alternative 3). A is a unit or house for young silkworms (UPUK), also called a larva room, while B is a cocooning room or a unit or house for silkworms (UPUB), which is located close to each other. C is the main room with 2 floors, where the first floor is for silkworm cultivation (cooking, oven, spinning, and reeling), while the second floor is for offices and meeting rooms. D is the warehouse room. The steam generator and tower are located between rooms A and D.

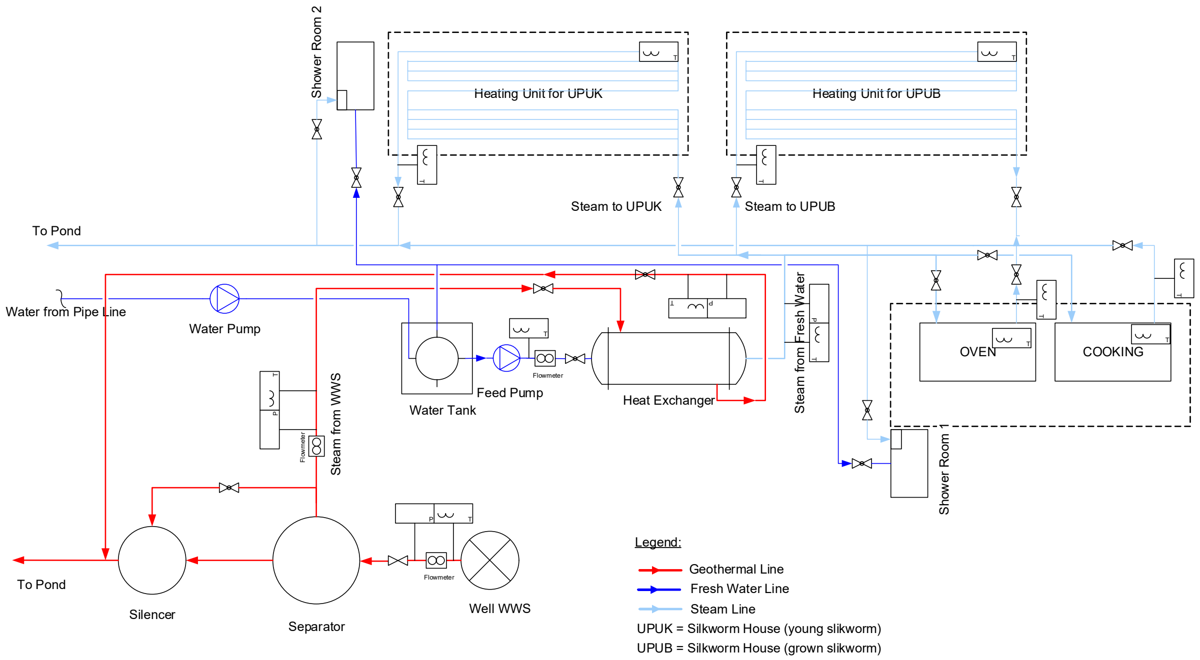

Fig.13: The layout of the piping system for the silkworm cultivation process

Fig. 13 shows a piping system for the silkworm cultivation process. The piping system is located on the first floor. Red, light blue, and dark blue markings are applied to pipes to distinguish flow systems. Starting at the WWS well and finishing at the pond or rejection, the red pipe is the geothermal system's pipe. The dark blue pipe distributes freshwater from the pipeline as feed water to the steam generator and restroom facilities. The light blue pipe is a steam pipe used to cultivate silkworms. Every piping system has temperature, pressure, and flow measurement sensors.

7. Community development program

To assist the community in creating a silkworm culture business and producing silk thread, the strategy for community development management relies heavily on geothermal energy. In this strategy, geothermal developers, in this case, Star Energy Limited, do not anticipate economic gains from this activity. Still, Star Energy Limited will contribute to the growth of the local community by utilizing existing geothermal energy without interfering with the field's principal power-generating business. Some scenario management patterns for direct use in community development include the following:

Scenario 1

Fig. 14 demonstrates that the geothermal developer provides all equipment and facilities for direct use while management is delegated to other parties, including cooperative business groups. In operation, however, the equipment manager remains accountable to the geothermal developer. Geothermal developers provide free supplies of geothermal fluid (steam or brine) to third parties, while communities and community groups pay a charge to utilize the available facilities (the amount is not greater than the previous energy cost or, according to a mutual agreement). Energy costs/fees and subsidies from geothermal developers cover operational expenses for geothermal energy-using equipment and facilities. In this manner, individuals can cut their energy expenditures and produce silk threads of higher quality

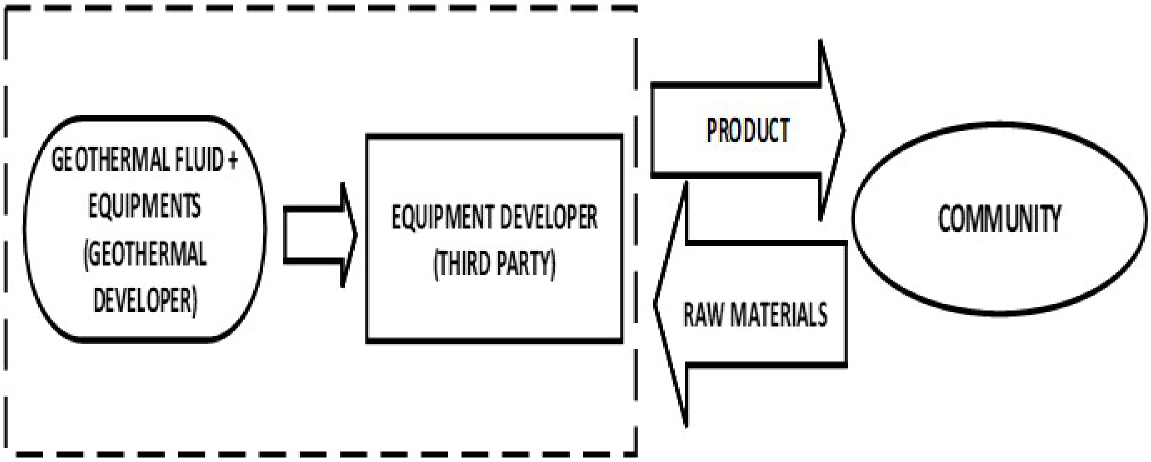

Fig. 14: Scenario 1 of community development management plan

Scenario 2

Fig. 15 shows that the geothermal developer provides all equipment and facilities for direct use while the management is handed over to a third party. These third parties are not responsible for geothermal developers but are carried out with the community. Even though a third party is not directly accountable for geothermal development, it must obtain approval from geothermal development for its operations, especially for the supply of steam or brine. Third parties and the community managing equipment and facilities for the direct utilization of geothermal energy also still receive a free collection of geothermal fluid (steam or brine) from geothermal developers.

Operational costs for managing geothermal direct utilization equipment and facilities are the responsibility of third parties and the community. However, it is hoped that geothermal developers will still provide subsidies, although in limited amounts. Therefore, operational costs are expected from the community's energy fee (the part that is not greater than the previous energy cost or, according to a mutual agreement).

Scenario 3

Geothermal developers provide geothermal fluid (steam or brine) free of charge, while the government offers equipment and facilities for the direct use of geothermal energy as a form of assistance. This scenario is shown in Fig. 16. The management of this facility can be handed over to a third party or directly to the community. However, according to their respective contributions and authorities, geothermal developers and the government are still involved.

The choice of one of the alternatives above in its implementation must be carefully considered by obtaining input from stakeholders to develop the direct use of geothermal energy. This management pattern will become a sustainable business activity if carried out with a revolving fund system to become an income-generating community development program capable of improving the community's welfare around the geothermal field.

To develop direct use of geothermal energy, selecting one of the abovementioned options must be carefully considered, with input from stakeholders. This management pattern will become a sustainable business activity if implemented with a revolving fund system to become a revenue-generating community development program that enhances the surrounding community's well-being.

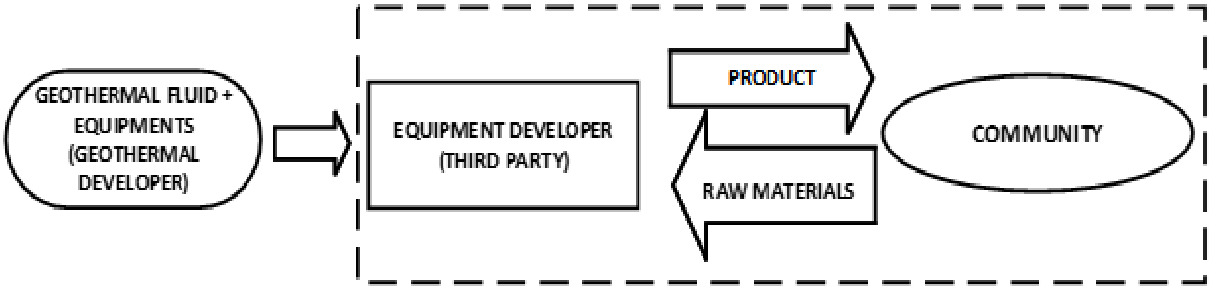

Fig. 15: Scenario 2 of the community development management plan

Fig. 16: Scenario 3 of the community development management plan

8. Conclusion

In conclusion, the vast geothermal resources in West Java provide a great opportunity for direct-use applications. Silkworm cultivation is a community economic activity that can be supported by utilizing geothermal fluids. The geothermal company "Star Energy Ltd." in Wayang Windu has provided community development assistance to the silkworm cultivation community, which can potentially replace coal as the primary energy source for the silk yarn industry. The estimated thermodynamics and key components of silkworm cultivation show that a non-commercial heating well, WWS, can meet the heat requirements for silk yarn production. The well can generate around 17 MW_t. The calculations indicate that 10 kilograms of cocoons require approximately 155.9 kW_t. A silkworm cultivation facility will need 3.7 MW_t of geothermal energy to produce 240 kg of cocoons per production cycle, which is equivalent to 0.5 kg of coal or 1.4 kg of carbon dioxide (CO_2). Therefore, the WWS well can supply the energy requirements of four of the seven silkworm cultivation houses in the Wayang Windu area. The WWS well is the steam generator's heat source for all silkworm cultivation processes. The planned silkworm-growing project is proposed to be located near WWS, accessible through public roads, and managed by a third party with the community's help. The proposed plan for managing community development relies on geothermal energy. The geothermal developer provides equipment and facilities for direct use, handing over management to third parties like business cooperatives. Overall, this project has the potential to benefit the community and promote the use of clean energy in the production of goods. This project is a good example of how geothermal energy can be utilized for community development without getting in the way of the field's main job of producing electricity.

Acknowledgements

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Nomenclature

UPUK	Young silkworm house
UPUB	Grown silkworm house
Q	Heat load (kW)
$\dot{Q}$	Average heat load (kW)
c_p	specific heat capacity (J kg^{-1} K^{-1})
T	Temperature (°C)
V	Volume (m^3/s)
Re	Reynold number (-)
Pr	Prandtl number (-)

OD	Outside Diameter (m)
WWC/D/E/S…	WW: Wayang Windu; C/D/E/S…: Capital of aphabet

Greek symbols

ρ	density (kg/m^3)

Subscripts

w	wall
n	number
o	outside

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